

Monodromy zeta-functions of deformations and Newton diagrams*

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Abstract

For a one-parameter deformation of an analytic complex function germ of several variables, there is defined its monodromy zeta-function. We give a Varchenko type formula for this zeta-function if the deformation is non-degenerate with respect to its Newton diagram.

1 Introduction

Let F be the germ of an analytic function on $(\mathbb{C}^{n+1}, 0)$, where $\mathbb{C}^{n+1} = \mathbb{C}_\sigma \times \mathbb{C}_{\mathbf{z}}^n$, σ is the coordinate on \mathbb{C} , and $\mathbf{z} = (z_1, z_2, \dots, z_n)$ are the coordinates on \mathbb{C}^n . The germ F provides a deformation $f_\sigma = F(\sigma, \cdot)$ of the function germ $f = f_0$ on $(\mathbb{C}^n, 0)$. We give formulae for the monodromy zeta-functions of the deformations of the hypersurface germs $\{f = 0\} \cap (\mathbb{C}^*)^n$ and $\{f = 0\}$ at the origin in terms of the Newton diagram of F . A reason to study deformations of hypersurface germs and their monodromy zeta-functions was inspired by their connection with zeta-functions of deformations of polynomials: [3].

Let A be the complement to an arbitrary analytic hypersurface Y in \mathbb{C}^n : $A = \mathbb{C}^n \setminus Y$. Let $V = \{F = 0\} \cap (\mathbb{C}_\sigma \times A) \cap B_\varepsilon$, where $B_\varepsilon \subset \mathbb{C}^{n+1}$ is the closed ball of radius ε with the centre at the origin. Let $\mathbb{D}_\delta^* \subset \mathbb{C}_\sigma$ be the punctured disk of radius δ with the centre at the origin. For $0 < \delta \ll \varepsilon$ small enough the restriction to V of the projection $\mathbb{C}^{n+1} \rightarrow \mathbb{C}_\sigma$ onto the first factor provides a fibration over \mathbb{D}_δ^* ([7]). Denote by V_c the fibre over the point c . Consider the monodromy transformation $h_{F,A}: V_c \rightarrow V_c$ of the above fibration restricted to the loop $c \cdot \exp(2\pi it)$, $t \in [0, 1]$, $|c|$ is small enough.

The zeta-function of an arbitrary transformation $h: X \rightarrow X$ of a topological space X is the rational function $\zeta_h(t) = \prod_{i \geq 0} (\det(\text{Id} - th_*|_{H_i^c(X; \mathbb{C})}))^{(-1)^i}$, where $H_i^c(X; \mathbb{C})$ is the i -th homology group with closed support.

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Definition. The zeta-function of the monodromy transformation $h_{F,A}$ will be called the monodromy zeta-function of the deformation f_σ on A : $\zeta_{f_\sigma|A}(t) = \zeta_{h_{F,A}}(t)$.

For a power series $S = \sum c_{\mathbf{k}} \mathbf{y}^{\mathbf{k}}$, $\mathbf{y}^{\mathbf{k}} = y_1^{k_1} \cdots y_m^{k_m}$, one defines its Newton diagram as follows. Denote by $\mathbb{R}_+ \subset \mathbb{R}$ the set of non-negative real numbers. Denote by $\Gamma'(S)$ the convex hull of the union $\cup_{c_{\mathbf{k}} \neq 0} (\mathbf{k} + \mathbb{R}_+^m)$. The Newton diagram of the series S is the union of compact faces of $\Gamma'(S)$. For a germ G on \mathbb{C}^m at the origin, its Newton diagram $\Gamma(G)$ is the Newton diagram of its Taylor series at the origin.

For a generic germ F on $(\mathbb{C}^{n+1}, 0)$ with fixed Newton diagram $\Gamma \in \mathbb{R}_+^{n+1}$ the zeta-functions $\zeta_{f_\sigma|(\mathbb{C}^*)^n}(t)$, $\zeta_{f_\sigma|\mathbb{C}^n}(t)$ are also fixed. We provide explicit formulas for these zeta-functions in terms of the Newton diagram Γ .

2 The main result (a Varchenko type formula)

Let F be a germ of a function on $(\mathbb{C}^{n+1}, 0)$. Let $\mathbf{k} = (k_0, k_1, \dots, k_n)$ be the coordinates on \mathbb{R}^{n+1} corresponding to the variables σ, z_1, \dots, z_n respectively. For $I \subset \{0, 1, \dots, n\}$ denote by \mathbb{R}^I , $\Gamma^I(F)$ the sets $\{\mathbf{k} \mid k_i = 0, i \notin I\} \subset \mathbb{R}^{n+1}$ and $\Gamma(F) \cap \mathbb{R}^I$ respectively.

An integer covector is called primitive if it is not a multiple of another integer covector. Let P^I be the set of primitive integer covectors in the dual space $(\mathbb{R}^I)^*$ such that all their components are strictly positive. For $\alpha \in P^I$, let $\Gamma_\alpha^I(F)$ be the subset of the diagram $\Gamma^I(F)$ where $\alpha|_{\Gamma^I(F)}$ reaches its minimal value: $\Gamma_\alpha^I(F) = \{\mathbf{x} \in \Gamma^I(F) \mid \alpha(\mathbf{x}) = \min(\alpha|_{\Gamma^I(F)})\}$ (for $\Gamma^I(F) = \emptyset$ we assume $\Gamma_\alpha^I(F) = \emptyset$). Consider the Taylor series of the germ F at the origin: $F = \sum F_{\mathbf{k}} \sigma^{k_0} z_1^{k_1} \cdots z_n^{k_n}$. Denote: $F_\alpha = \sum_{\mathbf{k} \in \Gamma_\alpha^I(F)} F_{\mathbf{k}} \sigma^{k_0} z_1^{k_1} \cdots z_n^{k_n}$.

Definition. A germ F of a function on $(\mathbb{C}^{n+1}, 0)$ is called non-degenerate with respect to its Newton diagram if for any $\alpha \in P^I$ the 1-form dF_α does not vanish on the germ $\{F_\alpha = 0\} \cap (\mathbb{C}^*)^{n+1}$ at the origin (see [9]).

For $I \in \{0, 1, \dots, n\}$ such that $0 \in I$, we denote:

$$\zeta_F^I(t) = \prod_{\alpha \in P^I} (1 - t^{\alpha(\frac{\partial}{\partial k_0})})^{(-1)^{l-1} l! V_l(\Gamma_\alpha^I(F))},$$

where $l = |I| - 1$, $\frac{\partial}{\partial k_0}$ is the vector in \mathbb{R}^I with the single non-zero coordinate $k_0 = 1$, and $V_l(\cdot)$ denotes the l -dimensional integer volume, i.e. the volume in a rational l -dimensional affine hyperplane of \mathbb{R}^I normalized in such way that the volume of the minimal parallelepiped with integer vertices is equal to 1. We assume that $V_0(\text{pt}) = 1$ and for $n \geq 0$ one has $V_n(\emptyset) = 0$.

Theorem 1 *Let F be non-degenerate with respect to its Newton diagram $\Gamma(F)$. Then one has*

$$\zeta_{f_\sigma|(\mathbb{C}^*)^n}(t) = \zeta_F^{\{0,1,\dots,n\}}(t), \quad (1)$$

$$\zeta_{f_\sigma|\mathbb{C}^n}(t) = (1-t) \times \prod_{I: 0 \in I \subset \{0,1,\dots,n\}} \zeta_F^I(t). \quad (2)$$

Remarks. 1. The equation (1) implies the equation (2) because of the following multiplicative property of the zeta-function. Let $h: X \rightarrow X$ be a transformation of a CW-complex X . Let $Y \subset X$ be a subcomplex of X . Assume that $h(Y) \subset Y$, $h(X \setminus Y) \subset (X \setminus Y)$. Then $\zeta_{h|_X}(t) = \zeta_{h|_{X \setminus Y}}(t) \times \zeta_{h|_Y}(t)$.

One can see that $\zeta_{f_\sigma|_{\{0\}}}(t) = (1-t) \times \zeta_F^{\{0\}}(t)$. In fact, in the case $\Gamma^{\{0\}} = \emptyset$ one has $\zeta_{f_\sigma|_{\{0\}}}(t) = (1-t)$, $\zeta_F^{\{0\}}(t) = 1$. Otherwise $\zeta_{f_\sigma|_{\{0\}}}(t) = 1$, $\zeta_F^{\{0\}}(t) = (1-t)^{-1}$.

2. The zeta-function $\zeta_{f_\sigma|_{\mathbb{C}^n}}(t)$ coincides with the monodromy zeta-function of the germ of the function $\sigma: \{F = 0\} \rightarrow \mathbb{C}_\sigma$ at the origin. The main theorem of [8] provides a formula for the zeta-functions of germs of functions on complete intersections in non-degenerate cases. One can apply this formula to the germ σ and verify that the formula (2) agrees with the one of M. Oka. But (2) can not be deduced from the result of M. Oka because the function σ doesn't satisfy the condition of "convenience" ([8, p. 17]).

Examples. 1. Let $F(\sigma, \mathbf{z}) = f(\mathbf{z}) - \sigma$. The monodromy zeta-function of the deformation f_σ coincides with the (ordinary) monodromy zeta-function $\zeta_f(t)$ of the germ f on $(\mathbb{C}^n, 0)$ (see, e.g., [9]). In this case the l -dimensional faces $\Gamma_\alpha^I(F)$ (where $l = |I| - 1 > 0$) are cones of integer height 1 over the corresponding $(l-1)$ -dimensional faces $\Gamma_{\alpha|_{\{k_0=0\}}}^{I \setminus \{0\}}(f)$. One has:

$$V_l(\Gamma_\alpha^I(F)) = V_{l-1}(\Gamma_{\alpha|_{\{k_0=0\}}}^{I \setminus \{0\}}(f)) / l$$

with $\alpha(\partial/\partial k_0) = \min(\alpha|_{\Gamma^{I \setminus \{0\}}(f)})$. This means that in this case the equation (2) coincides with the Varchenko formula ([9]).

2. For a deformation $F(\sigma, \mathbf{z})$ of the form $f_0(\mathbf{z}) - \sigma f_1(\mathbf{z})$ the fibre

$$(\{\sigma\} \times \{f_\sigma = 0\}) \cap B_\varepsilon$$

is the disjoint union of the sets

$$(\{\sigma\} \times \{f_0/f_1 = \sigma\}) \cap B_\varepsilon$$

and

$$(\{\sigma\} \times \{f_0 = f_1 = 0\}) \cap B_\varepsilon.$$

If $f_0(0) = f_1(0) = 0$, then $\zeta_{f_\sigma|_{\mathbb{C}^n}}(t) = (1-t) \times \zeta_{(f_0/f_1)|_{\mathbb{C}^n}}(t)$, otherwise $\zeta_{f_\sigma|_{\mathbb{C}^n}}(t) = \zeta_{(f_0/f_1)|_{\mathbb{C}^n}}(t)$ (the zeta-function of the meromorphic function f_0/f_1 : [2]).

For $I \subset \{0, 1, \dots, n\}$ such that $0 \in I$, and for a covector $\alpha \in P^I$, assume that the face $\Gamma_\alpha^I(F)$ has dimension l , where $l = |I| - 1 > 1$. Then $\Gamma_\alpha^I(F)$ is the convex hull of the corresponding faces $\Delta_{\alpha,0}^I = \{0\} \times \Gamma_{\alpha|_{\{k_0=0\}}}^{I \setminus \{0\}}(f_0)$ and $\Delta_{\alpha,1}^I = \{1\} \times \Gamma_{\alpha|_{\{k_0=0\}}}^{I \setminus \{0\}}(f_1)$, which lie in the hyperplanes $\{k_0 = 0\}$, $\{k_0 = 1\}$ respectively. It is not difficult to show (see, e.g., [4, Lemma 1]) that $V_l(\Gamma_\alpha^I(F)) = V_\alpha^I/l$, where

$$\begin{aligned} V_\alpha^I &= V_{l-1}(\Delta_{\alpha,0}^I, \dots, \Delta_{\alpha,0}^I) + V_{l-1}(\Delta_{\alpha,0}^I, \dots, \Delta_{\alpha,0}^I, \Delta_{\alpha,1}^I) + \\ &\quad + \dots + V_{l-1}(\Delta_{\alpha,0}^I, \Delta_{\alpha,1}^I, \dots, \Delta_{\alpha,1}^I) + V_{l-1}(\Delta_{\alpha,1}^I, \dots, \Delta_{\alpha,1}^I). \end{aligned}$$

Here V_{l-1} denotes the $(l-1)$ -dimensional Minkowski's mixed volume: see, e.g., [8]. Moreover, $\alpha(\partial/\partial k_0) = \min(\alpha|_{\Gamma^{I \setminus \{0\}}(f_0)}) - \min(\alpha|_{\Gamma^{I \setminus \{0\}}(f_1)})$, thus (2) coincides with the main result of [2].

3 A'Campo type formula

Proof of Theorem 1 uses an A'Campo type formula ([1]) written in terms of the integration with respect to the Euler characteristic ([3]).

For a constructible function Φ on a constructible set Z with values in a (multiplicative) Abelian group G its integral $\int_Z \Phi^{d\chi}$ with respect to the Euler characteristic χ is defined as $\prod_{g \in G} g^{\chi(\Phi^{-1}(g))}$ (see [10]). Further we consider $G = \mathbb{C}(t)^*$ to be the multiplicative group of non-zero rational functions in the variable t .

Let F be a germ of an analytic function on $(\mathbb{C}^{n+1}, 0)$ defined on a neighbourhood U of the origin. Let Y be a hypersurface in \mathbb{C}^n . Denote $S = (\mathbb{C}_\sigma \times Y) \cup \{\sigma = 0\}$. Consider a resolution $\pi: (X, D) \rightarrow (U, 0)$ of the germ of the hypersurface $\{F = 0\} \cup S$ at the origin, where $D = \pi^{-1}(0)$ is the exceptional divisor.

Theorem 2 *Assume π to be an isomorphism outside of $\pi^{-1}(U \cap S)$. Then*

$$\zeta_{f_\sigma|_{\mathbb{C}^n \setminus Y}}(t) = \int_{D \cap W} \zeta_{\Sigma|_{W \setminus Z}, x}(t)^{d\chi}, \quad (3)$$

where W is the proper preimage of $\{F = 0\}$ (i.e. the closure of $\pi^{-1}(V)$, $V = ((\{F = 0\} \cap U) \setminus S)$), $\Sigma = \sigma \circ \pi$, $Z = \pi^{-1}(\mathbb{C}_\sigma \times Y)$ and $\zeta_{\Sigma|_{W \setminus Z}, x}(t)$ is the monodromy zeta-function of the germ of the function Σ on the set $W \setminus Z$ at the point $x \in D \cap W$.

Proof. The map π provides an isomorphism $W \setminus (Z \cup \{\Sigma = 0\}) \rightarrow V$, which is also an isomorphism of fibrations provided by the maps Σ and σ over sufficiently small punctured neighbourhood of zero $\mathbb{D}_\delta^* \subset \mathbb{C}_\sigma$. Therefore the monodromy zeta-functions of this fibrations coincide, $\zeta_{f_\sigma|_{\mathbb{C}^n \setminus Y}}(t) = \zeta_{\Sigma|_{W \setminus Z}}(t)$ (the monodromy zeta-function of the "global" function Σ on $W \setminus Z$).

Applying the localization principle ([3]) to Σ we obtain:

$$\zeta_{f_\sigma|_{\mathbb{C}^n \setminus Y}}(t) = \int_{W \cap \{\Sigma=0\}} \zeta_{\Sigma|_{W \setminus Z}, x}(t)^{d\chi}. \quad (4)$$

The integration is multiplicative with respect to subdivision of its domain. One has $W \cap \{\Sigma = 0\} = (D \cap W) \sqcup ((W \cap \{\Sigma = 0\}) \setminus D)$. Thus the right hand side of (4) is the product $\left[\int_{D \cap W} \zeta_{\Sigma|_{W \setminus Z}, x}(t)^{d\chi} \right] \cdot \left[\int_{W \cap (\{\Sigma=0\} \setminus D)} \zeta_{\Sigma|_{W \setminus Z}, x}(t)^{d\chi} \right]$. The first factor coincide with the right hand side of (3); we prove that the second factor equals 1.

For a point $x \in D$, its neighbourhood $U(x) \subset X$ with a coordinate system u_1, u_2, \dots, u_{n+1} is called *convenient* if each of manifolds D, Z can be defined on $U(x)$ by an equation of type $\mathbf{u}^{\mathbf{k}} = 0$ and each of functions $\Sigma, \tilde{F} = F \circ \pi$ has the form $a \mathbf{u}^{\mathbf{k}}$, where $a(0) \neq 0$. One can assume that X is covered by a finite number of convenient neighbourhoods.

For an arbitrary convenient neighbourhood U_0 , choose an order of coordinates u_i on it such that $D = \{u_1 u_2 \cdots u_l = 0\}$.

Proposition 1 *The zeta-function $\zeta_{\Sigma|_{W \setminus Z}, x}(t)$ at a point $x \in U_0 \setminus D$ is well-defined by the coordinates $u_{l+1}, u_{l+2}, \dots, u_{n+1}$ of x .*

Proof. The germ of the manifold Z at the point x is defined by an equation $u_{l+1}^{k_{1,l+1}} \cdots u_{n+1}^{k_{1,n+1}} = 0$; in a neighbourhood of x one has $\tilde{F} = a u_{l+1}^{k_{2,l+1}} \cdots u_{n+1}^{k_{2,n+1}}$, $\Sigma = b u_{l+1}^{k_{3,l+1}} \cdots u_{n+1}^{k_{3,n+1}}$, where $a(x) \neq 0$, $b(x) \neq 0$, $k_{1,j} \in \{0, 1\}$; $k_{2,j}, k_{3,j} \geq 0$. The zeta-function $\zeta_{\Sigma|_{W \setminus Z}, x}(t)$ is well-defined by the numbers $k_{i,j}$, $i = 1, 2, 3$, $j = l+1, \dots, n+1$, which do not depend on u_1, \dots, u_l . \square

For a rational function $Q(t)$, we define a set $X_Q = \{x \in W \cap (\{\Sigma = 0\} \setminus D) \mid \zeta_{\Sigma|_{W \setminus Z}, x}(t) = Q(t)\}$. It follows from the proposition above that for any convenient neighbourhood U_0 we have $\chi(U_0 \cap X_Q) = 0$. Thus for all $Q(t)$ we have $\chi(X_Q) = 0$ and

$$\int_{W \cap (\{\Sigma=0\} \setminus D)} \zeta_{\Sigma|_{W \setminus Z}, x}(t)^{d\chi} = \prod_Q Q^{\chi(X_Q)} = 1.$$

\square

4 Proof of Theorem 1

Using the Newton diagram $\Gamma(F)$ of the germ F on $(\mathbb{C}^{n+1}, 0)$ one can construct an unimodular simplicial subdivision Λ of the set of covectors with non-negative coordinates $(\mathbb{R}^{n+1})_+^*$ (see, e.g., [9]). Consider the toroidal modification map $p : (X_\Lambda, D) \rightarrow (\mathbb{C}^{n+1}, 0)$ corresponding to Λ . Let $U \subset \mathbb{C}^{n+1}$ be a small enough ball with the centre at the origin, $X = p^{-1}(U)$, $\pi = p|_X$. Let $Y = \{z_1 z_2 \cdots z_n = 0\} \subset \mathbb{C}_z^n$. Then $S = (Y \times \mathbb{C}_\sigma) \cup \{\sigma = 0\}$ is the union of the coordinate hyperplanes of \mathbb{C}^{n+1} . Since F is non-degenerate with respect to its Newton diagram $\Gamma(F)$, π is a resolution of the germ $S \cup \{F = 0\}$ (see, e.g., [8]). Finally, π is an isomorphism outside of S , so the resolution (X, π) satisfies the assumptions of Theorem 2.

Compute the right hand side of (3). Let $x \in D \cap W$ be a point of the $(n-l+1)$ -dimensional torus T_λ corresponding to an l -dimensional cone $\lambda \in \Lambda$. Let λ be generated by integer covectors $\alpha_1, \dots, \alpha_l$ and let λ lie on the border of a cone $\lambda' \in \Lambda$ generated by $\alpha_1, \dots, \alpha_l, \dots, \alpha_{n+1}$. Let (u_1, \dots, u_{n+1}) be the coordinate system corresponding to the set $(\alpha_1, \dots, \alpha_{n+1})$. There exists a coordinate system $(u_1, \dots, u_l, w_{l+1}, \dots, w_{n+1})$ in a neighbourhood U' of the point x such that $w_i(x) = 0$, $i = l+1, \dots, n+1$ and $\tilde{F} = F \circ \pi = a u_1^{k_{1,1}} u_2^{k_{1,2}} \cdots u_l^{k_{1,l}} \cdot w_{n+1}^{k_{1,n+1}}$ (where $a(0) \neq 0$). The zero level set $\{\Sigma = 0\}$ is a normal crossing divisor contained in $\{u_1 u_2 \cdots u_l = 0\}$. Therefore $\Sigma = \sigma \circ \pi = u_1^{k_{2,1}} u_2^{k_{2,2}} \cdots u_l^{k_{2,l}}$. One has: $W \cap U' = \{w_{n+1} = 0\}$, $(Z \cup \{\Sigma = 0\}) \cap U' = \{u_1 u_2 \cdots u_l = 0\}$, thus $\zeta_{\Sigma|_{W \setminus Z}, x}(t) = \zeta_{g|_{\{u_i \neq 0, i \leq l\}}}(t)$, where g is the germ of the following function of n variables: $g(u_1, \dots, u_l, w_{l+1}, \dots, w_n) = u_1^{k_{2,1}} u_2^{k_{2,2}} \cdots u_l^{k_{2,l}}$.

Assume that one of the exponents $k_{2,1}, k_{2,2}, \dots, k_{2,l}$ (say, $k_{2,1}$) is equal to zero. Then g doesn't depend on u_1 . We may assume that the monodromy transformation of its Milnor fibre also doesn't depend on u_1 . Denote $h = g|_{\{u_1=0\}}$. The monodromy transformations of the fibre of $g|_{\{u_2 u_3 \cdots u_l \neq 0\}}$ and one of $h|_{\{u_2 u_3 \cdots u_l \neq 0\}}$ are homotopy equivalent, so $\zeta_{g|_{\{u_2 u_3 \cdots u_l \neq 0\}}}(t) = \zeta_{h|_{\{u_2 u_3 \cdots u_l \neq 0\}}}(t)$. On the other hand the multiplicative property of the zeta-function implies that $\zeta_{g|_{\{u_i \neq 0, i \leq l\}}}(t) \times \zeta_{h|_{\{u_2 u_3 \cdots u_l \neq 0\}}}(t) = \zeta_{g|_{\{u_2 u_3 \cdots u_l \neq 0\}}}(t)$ and thus $\zeta_{g|_{\{u_i \neq 0, i \leq l\}}}(t) = 1$.

Now assume that all the exponents $k_{2,1}, k_{2,2}, \dots, k_{2,l}$ are positive. Then the non-zero fibre of the function g doesn't intersect $\{u_1 u_2 \dots u_l = 0\}$, so $\zeta_{g|_{\{u_i \neq 0, i \leq l\}}}(t) = \zeta_g(t)$. In the case $l > 1$ one has $\zeta_g(t) = 1$. In the case $l = 1$ one has: $g = u_1^{k_{2,1}}$, $\zeta_g(t) = 1 - t^{k_{2,1}}$.

We see that the integrand in (3) differs from 1 only at points x that lie in strata of dimension n . From here on $l = 1$. If all the components of $\alpha = \alpha_1$ are positive, then $T_\lambda \subset D$. Otherwise, $T_\lambda \cap D = \emptyset$. From here on $\alpha \in P^{\{0,1,\dots,n\}}$ (see the definitions before Theorem 1).

Using the coordinates (u_2, \dots, u_{n+1}) on the torus $T_\lambda = \{u_1 = 0\}$ we obtain: $T_\lambda \cap W = \{Q_\alpha = 0\}$, where for the power series $F = \sum F_{\mathbf{k}} \sigma^{k_0} z_1^{k_1} \dots z_n^{k_n}$ we denote $Q_\alpha = \sum_{\mathbf{k} \in \Gamma_\alpha^{\{0,\dots,n\}}(F)} F_{\mathbf{k}} u_2^{\alpha_2(\mathbf{k})} u_3^{\alpha_3(\mathbf{k})} \dots u_{n+1}^{\alpha_{n+1}(\mathbf{k})}$. So $T_\lambda \cap W$ is the zero level set of the Laurent polynomial Q_α . Using results of [5], [6] we obtain: $\chi(T_\lambda \cap W) = (-1)^{n-1} n! V_n(\Delta(Q_\alpha))$, where $\Delta(\cdot)$ denotes the Newton polyhedron. Since the polyhedra $\Delta(Q_\alpha)$ and $\Gamma_\alpha = \Gamma_\alpha^{\{0,1,\dots,n\}}(F)$ are isomorphic as subsets of integer lattices, their volumes are equal: $V_n(\Delta(Q_\alpha)) = V_n(\Gamma_\alpha)$. In a neighbourhood of a point $x \in T_\lambda \cap W$ one has $\Sigma = a u_1^{\alpha(\partial/\partial k_0)}$, where $a(x) \neq 0$. Therefore $\zeta_{\Sigma|_{W \setminus x}}(t) = 1 - t^{\alpha(\partial/\partial k_0)}$. Thus one has:

$$\int_{T_\lambda \cap W} \zeta_{\Sigma|_{W \setminus x}}(t)^{d\chi} = (1 - t^{\alpha(\frac{\partial}{\partial k_0})})^{\chi(T_\lambda \cap W)} = (1 - t^{\alpha(\frac{\partial}{\partial k_0})})^{(-1)^{n-1} n! V_n(\Gamma_\alpha)}. \quad (5)$$

Multiplying (5) for all strata $T_\lambda \subset D$ of dimension n we get (1).

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